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**DEVELOPMENT AND APPLICATION OF NEW  
PSYCHOPHYSICAL METHODS FOR THE  
CHARACTERIZATION OF THE HANDFEEL AND  
COMFORT PROPERTIES OF MILITARY CLOTHING  
FABRICS**

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The analysis of fabric characteristics that contribute to military clothing comfort was addressed in a series of studies. Trained panel sensory descriptive data on 13 military fabrics were obtained using a standardized handfeel evaluation method. A labeled magnitude scale of comfort was developed from consumer magnitude estimates of the semantic meaning of 26 verbal phrases denoting different levels of comfort/discomfort. This scale was used by 36 consumers to rate the handfeel comfort of the 13 test fabrics. The descriptive sensory data and comfort data were then combined with Kawabata data obtained on a subset of the test fabrics and the data were analyzed using principal components analysis. Multiple regression analyses were performed on the component scores to predict consumer comfort from the sensory and instrumental data. The results showed a high degree of predictability of comfort responses from a combination of sensory and Kawabata parameters.

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## **Preface**

This report details joint studies undertaken by the Science and Technology Directorate and the Individual Protection Directorate of the Natick Soldier Center as part of the Center's overall program on military clothing comfort. With the change from material specifications of military uniforms and equipment to performance specifications of these items, the need arose to be able to index clothing comfort using an objective and standardized method of evaluation. To meet this need, the Industry-Government Working Group on Military Clothing Comfort was established to provide recommendations and guidance on how best to predict clothing comfort using standardized sensory or instrumental methods. As a result of these working group deliberations, a strategy was developed to assess a wide range of fabrics used by U.S. and other NATO countries for battledress uniforms. The first phase of this strategy involved the evaluation of selected fabrics for their sensory handfeel properties, their physical (instrumental) properties, and their perceived handfeel comfort using standardized methods of measurement. Using these data, predictive equations could be developed to predict uniform comfort from these standardized tests. The second phase of research would extend this predictive methodology to the comfort of battledress uniforms made from these fabrics and worn by soldiers in controlled wear trials.

This report describes the development of methods and procedures for use in the first phase of this research, as well as the results of testing conducted on the selected fabrics and the predictive relationships obtained between the sensory, instrumental and comfort properties of the fabrics. Based on the results of this research, fabrics have been selected for use in wear trials that are now being planned as part of the second phase of the overall research program.

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# DEVELOPMENT AND APPLICATION OF NEW PSYCHOPHYSICAL METHODS FOR THE CHARACTERIZATION OF THE HANDFEEL AND COMFORT PROPERTIES OF MILITARY CLOTHING FABRICS

## Introduction

### General Background

The United States Department of Defense (DoD) procures over 1.1 billion dollars of clothing and individual equipment each year. A large portion of these expenditures goes toward the purchase of Battle Dress Uniforms (BDU), the two-piece, camouflage uniforms worn by troops in combat, training and garrison situations. While the comfort of these garments has been a major consideration in their design and development, much of the research to date has focussed on the *thermal* comfort of the garments, because thermal stress is a major contributing factor to human performance degradation. More recently, focus has turned toward the less studied area of *tactile* comfort. This refocusing has been precipitated both by the knowledge that the BDU is worn on a daily basis in garrison situations, where heat stress is less of an issue than in combat, and the fact that procurement policy changes have moved DoD away from specifications of fabric composition and toward specifications based on functional or performance characteristics, e.g., durability and comfort criteria. In order to better understand and quantify the tactile comfort of military clothing and to determine predictive relationships between fabric properties, sensory experiences and consumer comfort, a research program was initiated to identify and define the critical factors contributing to the tactile comfort of military fabrics and to apply and/or develop advanced psychophysical methodologies by which to measure both fabric tactile properties and the comfort of fabrics and garments.

Although the sensory and comfort properties of textiles have influenced consumer clothing choices since man first sought protection from the elements, scientific study of the perceptual and affective responses to clothing did not originate until the early years of the past century. It was during this time that early investigators, such as Binns, Pierce, Winslow, Houghton and Yaglou, and others, began the systematic analysis of the subjective responses to textiles and clothing [1-5]. From these early efforts evolved the conceptual bases for the study of fabric "hand" and the analysis of the determinants of sensory, thermal, and overall clothing

comfort. While the next 50 years produced a growing volume of literature on these topics, the study of the human responses to clothing materials suffered from a lack of theoretical models to guide research in the field. As a result, the field was plagued by idiosyncratic and undefined terminology, a lack of operational constructs, confusion over the type of panelists to use, failure to adopt modern psychophysical techniques, and general confusion in communication about fabric attributes and qualities [6-9].

Beginning with the work of Fourt and Hollies [10], a better conceptualization of clothing comfort began to emerge, one that placed focus on three important components of clothing comfort: the person, the clothing, and the environment. Subsequent theoretical work by Slater [11,12], Rohles [13,14], Pontrelli [15], and Sontag [16] drew finer conceptual and empirical distinctions among the physical factors of both the garment and the environment, the physiological and sensory responses of the individual, psychological “filters” by which these latter responses are modified prior to conscious awareness, and the final affective response that we call comfort (see Branson and Sweeney [17] for a more detailed review of these theoretical developments). Within the context of this evolving theoretical framework, it became possible to better isolate the variables contributing to clothing comfort and to begin the refinement of techniques for measuring both these antecedent variables and the primary dependent variable of clothing comfort itself.

Measuring the subjective responses associated with clothing comfort, whether purely sensory (tactile) or affective (comfort) in nature, and whether felt on the body surfaces during wear of the garment or felt by the hand in response to handling of the fabrics, falls within the disciplinary areas of sensory psychology and psychophysics. In addition, when considering the sensations that arise from the contact of clothing fabrics with the skin, there are two fundamental psychological dimensions that must be considered. The first is qualitative (descriptive) and relates to the specific sensory quality or attribute that is being judged, e.g. roughness, stiffness, etc. The second is quantitative (intensive) in nature and relates to the perceived intensity of that sensation, e.g. *very rough*, *slightly stiff*, etc. Both dimensions of experience are involved in the perception of fabrics on the skin, and the methodologies used to identify and define these dimensions are critical elements determining the validity of the data and the types of conclusions that can be drawn from the data.

### **Recent Developments in Sensory Descriptive Handfeel Analysis**

Civille and Dus [9] reviewed previously published studies on the development of sensory handfeel attributes, terminology, and systems. Confirming several earlier analyses [6,7,18] they concluded that there were significant deficiencies in the published methods in terms of the development of primary (discrete and independent) tactile characteristics, the operationalization of terminology and evaluation procedures, proper scaling methodology, subject/panelist training, and general test protocols and controls. In response to this lack of standardization, Civille and Dus [9] developed the Handfeel Spectrum Descriptive Analysis (HSDA) method as a more analytical, comprehensive, and controlled approach to the sensory analysis of woven and non-woven fabrics. This method is modeled after similar and highly successful descriptive methods used for sensory analysis of other consumer products, e.g. foods, perfumes and skin care products [19,20]. The attribute terms and protocols for the HSDA method have been reviewed and refined by the Other Senses Task Group (E18.02.06.03) of ASTM Committee E-18 and the use of the method for the descriptive analysis of textiles has been reported previously [21,22].

The development of the HSDA method significantly enhanced the capability to define and study the qualitative aspects of sensory handfeel experience by establishing operationally defined terminology for primary attributes of sensory experience that are free of affective (good/bad) associations. Furthermore, by avoiding idiosyncratic terminology and the unnatural separation of the visual component of handfeel [6,23,24], the method minimizes differences between trained panelist ratings and consumer perceptions, significantly improving the likelihood of developing predictive relationships with consumer comfort. Since a major goal of the HSDA methodology is inter-laboratory standardization, the psychophysical scaling method that is used utilizes physical fabric standards as reference points along a 15-pt intensity scale for each handfeel attribute (the use of bipolar scales introduces confounding of attributes, as defined by the polar adjectives). So, for example, the intensity scale for fabric "stiffness" is anchored at the upper end by a cotton organdy standard, having a stiffness rating of 14.0, and at the lower end by a 50/50% polyester/cotton single knit fabric, having a stiffness rating of 1.3. Other fabrics define intermediate points on the stiffness continuum, while other sets of fabric standards define the intensity scales for other attributes [9,25]. Such stimulus-referenced or "learned" rating scales are widely used in commercial sensory evaluation and are particularly effective in helping to

conceptualize and define the stimulus dimension of interest. In addition, these scales have been shown to reduce intersubject variability [26], and can be easily transferred from one subject group to another, thereby ensuring high inter-laboratory reliability.

### **Comfort and Comfort Scaling**

Although a valid and reliable system for quantifying the descriptive handfeel attributes of fabrics is a logical prerequisite for identifying the fabric attributes that contribute to clothing comfort, no less important is a reliable and valid measure of comfort itself. Unlike tactile attributes, comfort is not a sensory dimension. It is not associated directly with any single human sense organ. Rather, it is an evaluative or affective dimension, similar to liking. Thus, there is no underlying physical dimension of the stimulus that varies continuously and is monotonic with the perception of comfort. The same stimulus can elicit different comfort responses from different individuals. For example, one individual may feel that a particular fabric, e.g., wool, is comfortable, while another person might deem it extremely uncomfortable. As a result, it is not possible to define a scale of comfort based on physical standards that are meaningful to all users. In addition, comfort is an affective dimension, and is only appropriately judged by untrained consumers. This requires a method for scaling comfort that is simple and unencumbered by the necessity for training or complex instructions.

In mathematics there are four discrete levels of measurement that can be used to index the quantitative relationships among objects. In increasing order of mathematical refinement, they are 1) nominal scaling (naming with numbers), 2) ordinal scaling (assigning rank), 3) interval scaling (intervals between numbers define equal quantities of the measured object/dimension), and 4) ratio scaling (there is a true zero point and the ratios among the numbers have meaning in terms of the measured objects/dimension). For the purpose of rating the sensory or affective experiences of individuals, a type of scale known as a category scale is the most common. These scales are characterized by a series of labeled points or categories. Individuals rate their subjective sensations by placing them into one of several available descriptive categories. Since less than five categories can result in a loss of discrimination sensitivity, the number of categories is typically around 9-10 [27], but can be much greater [25]. Several of the best known category scales for evaluating clothing sensations and/or comfort are Hollies' Subjective Comfort Rating Chart [28, 29], which uses both a category scale of intensity (partially, mildly, definitely,

totally) and the 13 point McGinnis category scale of comfort, and Gagge, et al.'s, [30] scale of comfort sensation (comfortable, slightly uncomfortable, uncomfortable, very uncomfortable). The reasons for the widespread use of category scales to measure not only subjective comfort, but a variety of other psychological dimensions, include their simplicity, versatility, ease of use by subjects, and their good reliability.

In spite of these advantages, there are significant problems associated with the use of category scales. Although it is often assumed that the points on a numbered category scale represent equal subjective intervals, that is, the perceived difference in comfort (stiffness, etc.) between a rating of 1 and 3 on the scale is equal to the perceived difference in comfort (stiffness, etc.) between a rating of 3 and 5 on the scale, this is not always the case [31]. On labeled category scales, subjects attend primarily to the word labels and not to the numbers [32]. In these cases, unless the verbal labels are chosen on the basis of extensive testing to verify that such differences as those between "slightly comfortable" and "moderately comfortable" are the same as those between "moderately comfortable" and "extremely comfortable", then the scale cannot be considered an interval scale, but merely an ordinal scale. This has implications for the type of statistics to be applied to the data (non-parametric vs. parametric). In addition, both the range and frequency of stimuli to be evaluated can significantly influence category scale ratings [33, 34].

Another common problem with category scales is that subjects tend not to use the end categories, because they fear that if they use them to describe one sensation and then they experience an even more extreme sensation, they will have no rating left to assign to the more extreme sensation [31, 35]. As a result of this "category end effect," seven-point category scales are essentially reduced to five-point scales, five-point scales to three-point scales, etc. A further complication occurs in those cases where the category scale is bi-directional and utilizes a "neutral" category. The use of such categories has been shown to encourage subjects to be non-committal in their responses, i.e., they overly rely on this "safe" category [36]. Elimination of the neutral category has been shown to increase the efficiency of category scales [37].

An alternative approach to the psychophysical scaling of perceived intensity that avoids the above problems, while providing ratio level data, was developed by S.S. Stevens [38]. Stevens believed that sensory intensity could only be measured accurately using ratio scales. Working on this assumption, he developed a ratio method in which subjects were allowed to

assign their own internal numbers to represent the magnitude of their sensations. He named the method “magnitude estimation” [38, 39]. Magnitude estimation avoids the major problems of category scaling by providing an unbounded upper limit for ratings. In addition, because magnitude estimation uses a true zero point of sensation and because all judgments are made relative to one another in a ratio manner (e.g., stimulus X is three times (one-half, etc.) as stiff (comfortable, etc.) as stimulus Y), the resultant data provide a ratio scale of the subjective dimension being evaluated, allowing for valid parametric analyses of the data.

In several studies examining the human sensory and comfort responses to clothing and textiles, magnitude estimation has been successfully used as a ratio scale measure of tactile responses [40-43]. Although this technique significantly increases the ability to accurately quantify subjective sensations, magnitude estimation requires that sensations be directly compared to one another, thereby precluding judgments that must be made over extended time periods. In addition, magnitude estimation requires detailed instruction for proper use and time-consuming normalization of the data prior to statistical analysis. More recently, these practical limitations of magnitude estimation have been eliminated by the development of semantic ratio scales (often called “labeled magnitude scales”). These scales commonly take the form of visual analogue or “line” scales, but they possess anchored verbal labels that define a ratio scale of sensory magnitude. This stands in contrast to unlabeled visual analogue scales, e.g., [44], which rely on the instructional set to create the ratio scale, but constrain ratings by having a circumscribed line length. The first such scale of this type was the “Borg” scale of perceived exertion [45]. However, similar labeled magnitude scales have been developed for both sensory [46] and affective [47] continua.

The above developments in psychophysical methodology that enable better quantification of both the descriptive aspects of handfeel sensations and the quantification of the affective dimension of handfeel experience open the possibility of a more well-grounded psychophysical approach to the study of the sensory and comfort characteristic of clothing fabrics. Combining these new sensory methodologies with established instrumental measures of fabric characterization, e.g., the Kawabata [48-50] system now makes it possible to develop better predictive relationships between sensory, instrumental, and comfort measures of fabrics.

## Objectives

With this in mind, a multiphase research program was initiated to (1) establish a standardized methodology for the assessment of the sensory tactile characterization of military fabrics, (2) to develop a labeled affective magnitude scale specific for rating fabric/clothing comfort, (3) to apply the methods developed in (1) and (2) to the characterization of a variety of military fabrics, and (4) to develop predictive relationships between the tactile attributes of the fabrics, their instrumental properties, and their perceived comfort.

### **Phase 1: Establishment of a Descriptive Profile Panel for Assessing Fabric Handfeel: Descriptive Profiles and Panel Reliability/Sensitivity**

The ability to reliably describe the sensory handfeel properties of clothing fabrics is essential to understanding the contribution of fabric characteristics to clothing comfort. In order to acquire these data on a continuing basis, the U.S. Army Natick Soldier Center (NATICK) took the necessary steps to train, develop, and maintain an in-house, sensory descriptive handfeel panel. Upon completion of training, the sensitivity and reliability of the panel was assessed.

**Methods:** Fifteen panelists (10 females, 5 males) were selected from volunteer employees at NATICK. Panelists were chosen on the basis of interest, availability, and successful completion of a screening test to establish minimum tactile acuity i.e., the ability to detect differences in the magnitude of selected tactile attributes [9]. Such screening was necessary because tactile acuity/sensitivity has been shown to vary as a function of age [51], degree of skin hydration/wettedness [52], dermatitis, and other factors. The selected panelists included both individuals working in the area of materials and textiles, as well as others.

Panelists participated in a six month training program that consisted of 1) a one-week training program on the basic methodology and evaluation techniques employed in the Handfeel Spectrum Descriptive Analysis Method [9] and exposure and practice with operational attribute definitions and a series of fabric intensity scales for each of 17 different sensory handfeel attributes (4 related to fabric and surface geometry, 10 related to mechanical properties and 2 to sound properties), 2) two months of twice-weekly panel meetings to reinforce these concepts, attribute definitions, and rating scales, 3) a second one-week training period in which the 17 attribute definitions were tailored to the specific nature of the military clothing fabrics to be used

in subsequent testing (Table 1), the final list of operational techniques of evaluation for each attribute were developed (Table 2), and a new set of fabrics were selected to serve as physical standards to define intensity scales for each attribute (Table 3), and 4) 3 months of bi-weekly practice sessions to solidify definitions and reduce between-panelist variability.

In order to assess the reliability and sensitivity of the HSDA method in combination with the panel training procedures, a test-retest reliability study was conducted at the completion of training. Three fabrics were selected for evaluation: a jersey knit fabric, a polyester/wool serge fabric (MIL-C-823), and a Tencel® ripstop poplin fabric. Choice of fabrics was based on the desire to represent as wide a range of tactile attributes as might be encountered in future testing and to include two similar and one dissimilar (jersey knit) fabric. The 3 test fabrics were evaluated by the panel on two separate occasions separated by a two-week interval. In addition, two of the test fabrics (Tencel® ripstop poplin and polyester/wool surge fabric) were tested again, six months later to assess long term reliability. All testing was conducted in a textile conditioning room at a temperature of  $70 \pm 1.4$  F and at  $65\% \pm 1.3$  RH. Testing was conducted at large open tables with smooth, black, stone-top surfaces (Figure 1). Panelists evaluated test samples on their “face” (labeled) surface, independently, and in random order using the 17 attribute definitions (Table 1) and intensity standards (Table 3) developed during training. All fabrics were laundered five times in accordance with American Association of Textile Chemists and Colorists (AATCC) test method #96, test condition IIIc, tumble dry (option A). After laundering the fabric was cut into 30cm x30cm swatches, with edges parallel to the fabric warp and filling directions. All edges were serrated to prevent raveling.

**Results/Discussion:** Figs 2a, b & c show the descriptive attribute ratings for the two samples that were evaluated during all 3 test sessions (a, b) and the one fabric tested during two separate sessions (c). Fig 2d shows the average panel data for all three fabrics. Looking at the fabric profiles in Fig 2, one can observe significant differences in the attribute profiles between different fabrics (Figure 2d), but a high degree of similarity in the profiles obtained for the same fabrics on different dates of testing (Figs 2a, b, c). For example, in Fig. 2d, it can be observed that the poly/wool serge fabric differed greatly from the Tencel® ripstop on such attributes as “grainy,” “gritty,” “thickness,” “force to gather,” “stiffness,” and the “intensity of compressive

**Table 1. Definitions of fabric handfeel attributes \***

Grainy	The amount of small, round particles in the surface of the sample.
Gritty	The amount of small, abrasive, picky particles in the surface of the sample.
Fuzziness	The amount of pile, fiber, fuzz on the surface of the sample.
Thickness	The perceived distance between the thumb and index finger (when the sample is placed between the two).
Tensile Stretch	The degree to which the sample stretches from its original shape.
Hand Friction	The force required to move the palm of the hand across the surface of the sample.
Fabric-Fabric Friction	The force required to move the fabric over itself.
Depression Depth	The amount that the sample depresses when downward force is applied.
Springiness	The rate at which the sample returns to its original position after the downward force is released.
Force to Gather	The amount of force required to compress the gathered sample into the palm.
Stiffness	The degree to which the sample feels pointed, ridged and cracked; not pliable.
Force to Compress	The amount of force required to compress the gathered sample into the palm.
Fullness/Volume	The amount of material felt in the hand .
Compression Resilience Intensity	The perceived force with which the sample exerts resistive pressure against the cupped hands.
Compression Resilience Rate	The rate at which the sample returns to its original shape or the rate at which the sample opens after compression.
Noise Intensity	The loudness of the noise.
Noise Pitch	The pitch (frequency) of the noise.

\* See Table 2 for the specific operational techniques by which each attribute is evaluated.

**Table 2. Operational techniques for the evaluation of handfeel attributes.**

**Grainy, Gritty:**

Lay sample flat on the table; evaluation side up. Place wrist on the table top; move index and middle fingers across the entire surface (1.0 inch from the edge) lightly from left to right using the weight of the hand; rotate sample to stroke along in all four directions of the sample.

**Fuzzy:**

Lay sample flat on the table; evaluation side up. Place heel of hand on the table top; rotate index finger lightly on surface in small quarter size circles at several locations.

**Thickness:**

Hold sample corner between thumb and index finger of non-dominant hand. Using light pressure, run fingers along the perimeter of the sample approximately 1 inch from edge. Run fingers along the width and length of the sample. There should be no sample distortion.

**Tensile Stretch:**

Grasp sample near edges with both hands; pull sample squarely and evenly across the width. Rotate sample 90° and repeat. Rate the direction with the most amount of stretch.

**Hand Friction:**

Lay sample flat on table top; place palm flat on fabric; using weight of hand and forearm, move hand horizontally across the surface in all four directions parallel to the edges.

**Fabric to Fabric Friction:**

Fold fabric in half with the top (evaluation) surfaces facing each other; grasp open end between thumb and fingertips; move the fabric over itself with rotating motion.

**Depression Depth and Springiness:**

Place sample flat on table top; fold sample in quarters; using finger tips press down gently on center of folded square; release the downward force.

**Force to Gather:**

Lay sample flat; place dominant hand on top of sample; position so the fingers are spread and pointing toward the top of the sample (1 1/2" from the edge) gather sample with fingers toward palm.

**Stiffness:**

Using other hand, feel the fabric extending from cupped hand.

**Force to Compress:**

Using other hand, press sample into cupped hand, close hand and compress.

**Fullness/Volume:**

Close hand slightly and manipulate by rotating sample in palm.

**Compression Resilience - Intensity and Rate:**

Place dominant hand on top of fresh sample; gather sample with fingers toward palm; cup opposite hand over the gathered sample; contain gathered sample between two cupped hands. Gently compress 5 times. Open hands.

**Noise Intensity and Pitch:**

Gather fabric into palm with fingers opened slightly; rotate sample gently while holding hand with sample next to ear.

**Table 3. Fabric reference standards defining intensity scales for each handfeel attribute.**

<b><u>FABRIC REFERENCE STANDARDS</u></b>						
<b><u>ATTRIBUTE</u></b>	<b>R1</b>	<b>R2</b>	<b>R3</b>	<b>R4</b>	<b>R5</b>	<b>R6</b>
Grainy	1.3	4.0	6.5	13.1	12.2	4.6
Gritty	0.0	1.3	1.2	4.2	14.3	4.8
Fuzzy	16.6	14.3	0.0	1.5	4.7	7.0
Thickness	13.0	28.0	2.0	7.0	8.0	4.5
Tensile Stretch	12.9	16.0	0.0	0.0	0.0	1.0
Hand Friction	13.3	12.0	3.0	5.5	8.0	10.5
Fabric to Fabric Friction	10.5	13.0	1.0	2.5	5.0	9.0
Depression Depth	13.3	18.3	0.0	0.0	0.8	3.6
Springiness	10.5	13.7	0.0	0.0	0.3	4.0
Force to Gather	3.5	7.5	1.6	5.7	13.0	6.0
Stiffness	1.0	3.4	1.6	6.6	13.5	5.3
Force to Compress	5.0	12.0	1.1	5.0	13.5	5.0
Compression Resil: Int.	3.0	5.5	1.3	7.4	14.0	6.5
Compression Resil: Rate	1.4	2.3	6.3	9.4	11.2	9.8
Fullness/Volume	11.5	16.0	1.5	7.1	11.5	7.1
Noise Intensity	1.5	1.0	6.4	12.0	15.0	5.0
Noise Pitch	1.5	1.0	7.9	7.0	13.0	3.0

**Reference Fabric Codes:**

R1 100 Series Polar Fleece-double velour, 100% polyester, 5.7 ounces/sq.yd, source: Malden Mills, Inc.  
R2 300 Series Polar Fleece-double velour, 100% polyester, 10 ounces/sq.yd, source: Malden Mills, Inc.  
R3 2oz Nylon (parachute fabric) - MIL-C-7020, cloth, parachute, nylon, ripstop and twill weave  
R4 Ballistic Nylon - MIL-C-44043, cloth, ballistic, nylon, lightweight, water repellent treated  
R5 1000 Denier Cordura Nylon - MIL-C-43734, cloth, duck, textured nylon  
R6 Nomex, Oxford Weave - MIL-C 43842

resistance.” Even larger differences can be seen in comparing the jersey knit fabric to the other two fabrics. Yet ratings of attributes for each fabric evaluated on multiple occasions (Figs 2a, b, c) were very similar. Pearson product-moment correlations were calculated across mean attribute ratings for each fabric rated on the different test days. The correlation coefficients between fabrics tested two weeks apart were .98 (poly/wool serge), .93 (Tencel® ripstop) and .98 (jersey knit). Correlations of panel ratings for the same fabrics by attribute ranged from .93 -.98, depending upon the attribute examined.

For the two fabrics tested again six months later, the correlation coefficients between each of the first two sessions and the third were .94 and .95 (poly/wool serge) and .89 and .93 (Tencel® ripstop), indicating only a minor drop in test-retest reliability over the six-month period.

From these data it was concluded that the HSDA methods, in conjunction with the panel training program outlined above, resulted in a sensory handfeel evaluation method that was highly sensitive and reliable over extended periods of time. Having established this capability to reliably index the sensory handfeel attributes of test fabrics, Phase 2 research commenced.

## **Phase 2: Descriptive Analysis of Military Fabrics**

As discussed in the Introduction, a wide variety of fabrics are used in military clothing by different forces within the U.S. Department of Defense, as well as by different foreign military forces. While durability and other functional criteria are important in selecting fabrics for use in military garments, the comfort of the garment to the wearer is also an important criterion. As part of a larger program to establish performance criteria for military clothing comfort, 13 fabrics used in U.S., British, Canadian and Australian military garments were assembled. The purpose of this phase of research was to quantify the handfeel attributes of these fabrics in order to characterize differences among them and to establish a sensory data base from which fabric attributes could be analyzed for their contribution to the handfeel comfort of the fabrics (see Phase 4).

**Methods:** The descriptive analytic handfeel methods and panel described in Phase 1 were utilized to characterize the test fabrics. Thirteen military test fabrics (Table 4) were evaluated over the course of several months of testing. The fabrics were chosen to represent a



Figure 1. View of sensory panel testing facility.

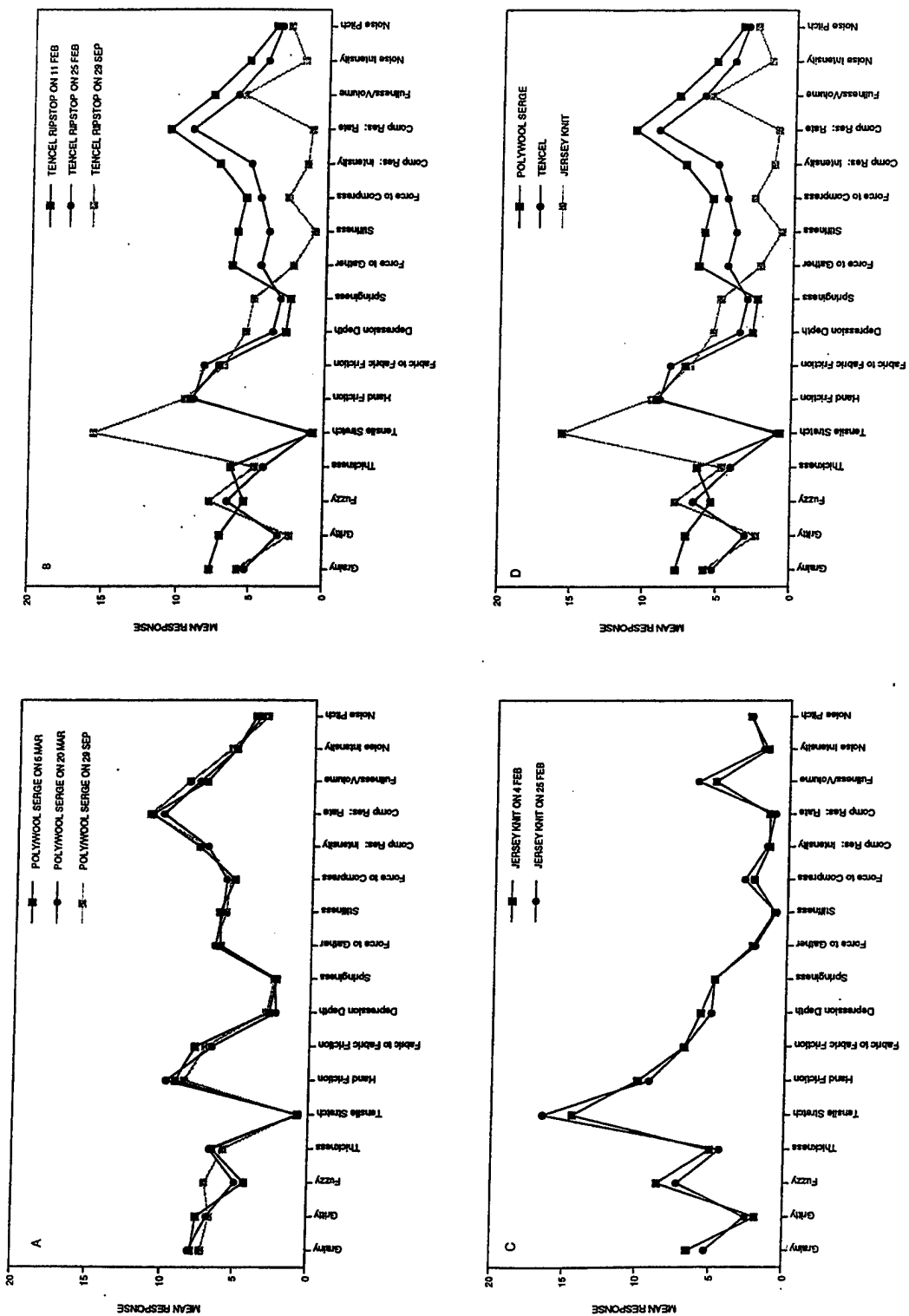


Figure 2. Mean panel ratings of handfeel attributes obtained on each of several different test sessions for poly/wool serge (a), Tencel ripstop poplin (b), and a jersey knit fabric (c). Panel d shows the ratings for each fabric averaged over test sessions.

**Table 4. Fabrics used in Phase 2 and Phase 5 research.**

<b><u>Fabric Composition</u></b>	<b><u>Sample Code</u></b>
50%/50% Nylon/Combed Cotton, Ripstop Poplin Weave	10R
50%/50% Nylon/Polyester, Oxford Weave (Australian)	11A
50%/50% Nylon/Cotton, Twill Weave	12T
92%/5%/3% Nomex, Kevlar, P140, Plain Weave	13P
100% Cotton, Twill Weave (Former Flame Retardant Treated)	14N
77%/33% Cotton Sheath/Synthetic Core, Twill (U.K.)	15B
100% Combed Cotton, Ripstop Poplin (Former Hot Weather BDU)	16C
65%/35% Wool/Polyester, Plain Weave. (Canada-Unlaundered)	17C
65%/35% Wool/Polyester, Plain Weave. (Canada-Laundered)	18L
92%/5%/3% Nomex, Kevlar, P140, Oxford Weave	19N
Carded Cotton Sheath/Nylon Core, Plain Weave (Canada)	20J
100% Pima Cotton Ripstop Poplin (experimental)	124
50%/50% Nylon Carded Cotton Ripstop Poplin Weave	176

wide range of tactile (and likely comfort) characteristics to be found in U.S. and foreign military uniforms. Of these 13, 8 fabrics had also been down-selected for use in future wear trials and for subsequent evaluation of their mechanical properties using the Kawabata (KES-F) system of fabric testing. Due to the large number of samples and the desire for multiple replicates, a maximum of four fabrics were evaluated during any panel session. Each fabric evaluation was replicated 3 times under the same testing conditions as described in Phase 1.

**Results/Discussion:** Figs. 3 and 4 show the sensory handfeel profiles for 8 of the 13 test fabrics. These eight were selected for graphical representation, since they are the same fabrics that were targeted to be examined in subsequent phases of testing. Fig. 3 shows four of these eight fabrics. Two of the fabrics are currently used in military battle dress uniforms (BDU).

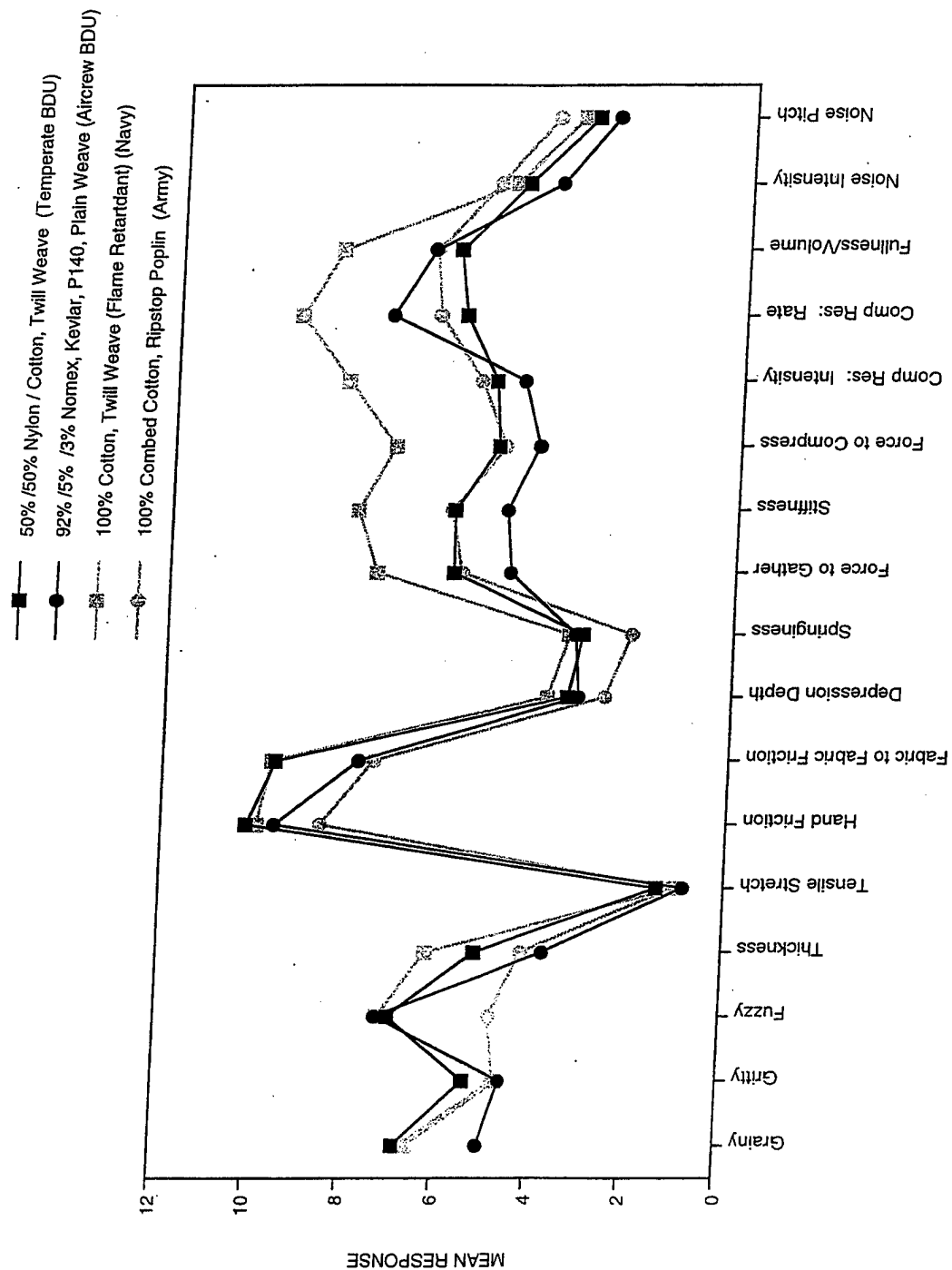


Figure 3. Mean panel ratings of handfeel attributes averaged over three replicates for four of the eight fabrics tested in Phase 2.

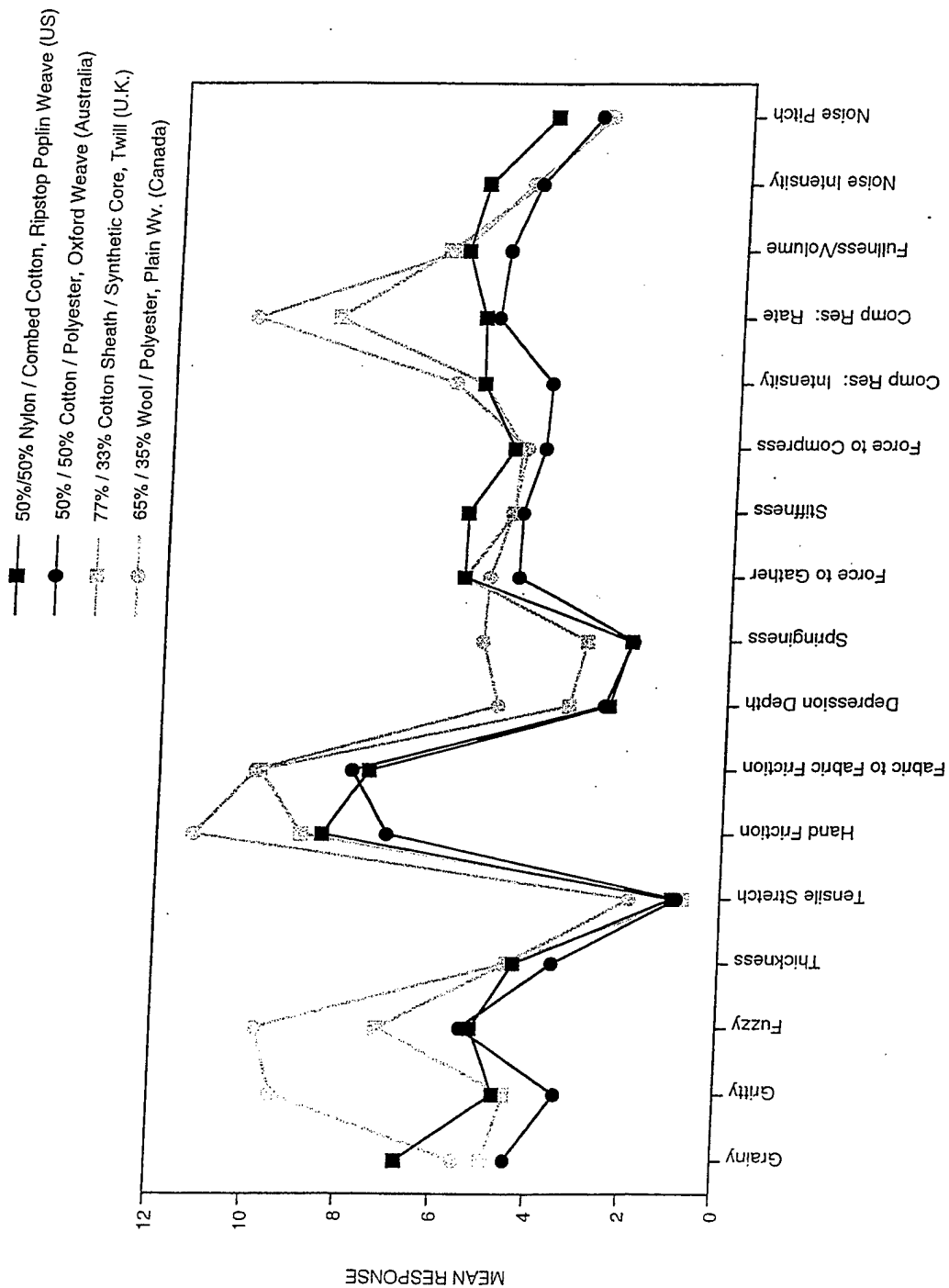


Figure 4. Mean panel ratings of handfeel attributes averaged over three replicates for the remaining four of the eight fabrics tested in Phase 2.

One is used in the U.S. Army Aircrew BDU (black circles), the other is used in the Temperate BDU (black squares). The other two fabrics for which data are depicted are materials formerly used in U.S. Navy coveralls (gray squares) and in the U.S. Army Hot Weather BDU (gray circles).

As can be seen, the sensory differences between the fabrics currently used in the Army Aircrew and the Temperate BDUs (black circles/squares) are relatively small. The fabric formerly used in the Army Hot Weather BDU (gray circles) is somewhat similar, but differs greatly from the former two in “fuzziness” and tends to be lower on several other attributes, e.g., “hand friction,” “depression depth” and “springiness”. On the other hand, the Navy fabric (gray squares) is quite different in its handfeel characteristics from each of the other fabrics. In particular, the Navy material is “thicker,” has greater “force to gather,” “stiffness,” “compressive resilience” and “fullness/volume,” than any of the other fabrics. The Army flame-resistant fabric exhibits some similar sensory properties, e.g. in terms of “fuzziness”, “tensile stretch”, “hand friction”, “depression depth” and “springiness”, but is a thinner, much smoother (less grainy) fabric, has lower “force to gather”, “stiffness”, and “compressive resistance” characteristics than the Navy material.

Fig. 4 shows a different combination of fabrics. Again, large differences can be seen in the handfeel profiles for the various fabrics. Table 5 shows the results of ANOVAs conducted on each handfeel attribute for the eight fabrics shown in Figs 3 and 4, along with the number of statistically significant subsets of samples (based on Newman-Keuls test of differences among means). As can be seen by the highly significant F values, all of the 17 handfeel attributes discriminated among the test fabrics. Several of the attributes, such as “hand friction,” “force to compress,” and both the “intensity and rate of compression resilience,” significantly differentiated the eight fabrics into as many as five distinct subsets of fabrics. Several other attributes differentiated three or four subsets. Of the three attributes with somewhat lower F values, “tensile stretch,” noise intensity” and “noise pitch,” an examination of Figs 3 and 4 reveals that few of the eight fabrics showed any tensile stretch. In contrast, the intensity of the sound attributes for these fabrics, although low, were as high or higher than other attributes that showed better discrimination among the fabrics, e.g., depression depth.

Table 6 shows the statistically significant ( $p < .05$ ) Pearson product-moment correlations coefficients greater than .90 among all possible pairings of the 17 handfeel attributes (136 coefficients). As can be seen, there are several distinct and logical groupings of the handfeel

**Table 5. F values, p values, and number of significant subsets of the 8 test fabrics for each of the 17 handfeel attributes.**

Attributes	F Value *	Number of significant subsets ( $p < .05$ )**
Grainy	11.47	3
Gritty	61.20	3
Fuzzy	42.51	3
Thickness	36.65	4
Tensile Stretch	8.47	3
Hand Friction	18.44	5
Fabric to Fabric Friction	18.47	2
Depression Depth	27.91	4
Springiness	22.27	3
Force to Gather	38.09	4
Stiffness	45.76	3
Force to Compress	39.72	5
Compression Resil: Intensity	50.14	5
Compression Resil: Rate	33.66	5
Fullness/Volume	19.53	3
Noise Intensity	8.28	3
Noise Pitch	6.58	2

\* All F-values are significant at  $p < .01$

\*\* Results of Newman\_Kuels post-hoc tests

attributes. For example, there is a highly significant association among the attributes “springy,” “fuzzy,” and “depression depth,” an association which is logically consistent with a fuzzy surface texture giving way to finger pressure and then springing back after the pressure is removed (ref Tables 1 and 2). Similarly, the triad of “force to gather,” “force to compress,” and “compression resilience intensity” is logically consistent with the operational techniques of gathering a fabric in the hand, compressing it, and perceiving the resistance to that compression (ref Tables 1 and 2). The third grouping of attributes in Table 6 (“force to gather,” “force to compress,” “thickness,” and “stiffness”) are logically associated by the degree to which the thickness and stiffness of a fabric determine the required forces to both gather and compress it in the hand. The high correlation between “noise intensity” and “noise pitch” is also consistent with the physics of sound production, where abrasive surface textures are likely to produce louder sounds with higher frequency. Only the association between “gritty” and “tensile stretch” appears to lack a logical explanation in terms of the definitions and techniques involved in their evaluation. The large differences among fabrics seen in Figs 3 and 4, combined with the demonstrated sensitivity (Table 5) and reliability (Figs 2a, b, c) of the HSDA methodology forms a strong empirical basis upon which to subsequently examine both the comfort of these fabrics and their mechanical parameters, so that the relationships among handfeel attributes, comfort and instrumental properties can be determined.

### **Phase 3: Development of a labeled magnitude scale for measuring comfort**

One of the critical tools required to evaluate the contribution of either the sensory handfeel or mechanical properties of fabrics to perceived comfort is a reliable and valid scaling instrument for judging subjective comfort. Although a number of comfort scales can be found in the literature, as noted in the Introduction, most of these are simple category scales that have been developed without adequate evidence of their reliability or validity. In addition, the scales are often constructed in such a way as to focus on only a single aspect of comfort (e.g. thermal), thereby limiting their capacity to be applied to a broad range of comfort situations. The purpose of the next phase of research was to develop a sensitive, reliable, valid, and user-friendly ratio scale of comfort, using previously developed labeled magnitude scales as models [46, 47].

**Table 6. Pearson correlation coefficients (>.90) among all pairs of handfeel attributes.**

<u>Attribute 1</u>	<u>Attribute 2</u>	<u>Pearson r *</u>
Springiness	Fuzzy	.98
Springiness	Depression Depth	.98
Fuzzy	Depression Depth	.96
Force to Compress	Force to Gather	.96
Force to Compress	Compression Resilience	.92
Force to Gather	Compression Resilience	.91
Force to Compress	Stiffness	.96
Force to Gather	Stiffness	.93
Force to Gather	Thickness	.94
Force to Compress	Thickness	.92
Noise Intensity	Noise Pitch	.96
Gritty	Tensile Stretch	.93

\* All coefficients are statistically significant ( $p < .05$ )

## Experiment 1

**Methods:** Thirty-five NATICK employees, none of whom were members of the descriptive handfeel panel, were recruited from a random list of volunteer consumer panelists and participated as subjects.

Word adjectives that could be used to modify the terms “comfortable” and “uncomfortable” in order to reflect differences in the magnitude of the comfort-discomfort dimension were compiled from previous scaling literature and from standard English language resources. The adjectives “greatest imaginable” and “greatest possible” were included to define scale values commensurate to a common fixed end-point of positive and negative affective experience, as utilized in previously developed labeled magnitude scales [45, 46, 47]. These adjectives were used to create forty-one word phrases, which in combination with two non-polar terms (“neutral” and “neither comfortable nor uncomfortable”), resulted in a total of 43 phrases to be used in scale development. These phrases appear in the left-hand column of Table 7.

The forty-three phrases were printed on 8 x 20 cm sheets of paper and assembled in random order into testing booklets. Testing was conducted in a large room with open tables. Prior to the start of testing, subjects were provided with written instructions on the procedure to be used in scaling the semantic meaning of the phrases (see Appendix). Oral instructions with an example were also given to insure that all subjects were aware of and understood the instructions. Subjects sequentially rated each of the phrases appearing in the booklet to indicate the magnitude of comfort or discomfort connoted by the phrase using a modulus-free magnitude estimation procedure. In this procedure, subjects assign an arbitrary number to indicate the magnitude of comfort or discomfort reflected by the first phrase (positive numbers used for comfort, negative numbers for discomfort). Subjects then make all subsequent judgments relative to the first, so that if the second phrase denotes twice as much comfort as the first, a number twice as large would be assigned; if it denotes 1/3 as much comfort, a number 1/3 as large as the first would be assigned, etc. (See Appendix). All ratings were made in spaces provided directly on the individual pages of the testing booklet.

**Results/Discussion:** The geometric means and standard errors of the assigned magnitude estimates were calculated for each of the comfort/discomfort phrases after an equalization procedure [53] was applied. These data are shown in Table 7. Geometric means were used because magnitude estimates have been shown to be log-normally distributed [54]. As can be seen, the geometric mean magnitude estimates ranged from -351 for "greatest imaginable discomfort" to +367 for "greatest imaginable comfort," with the other phrases distributed between these two extremes. (The phrases "neutral" and "neither comfortable nor uncomfortable" were assigned zero ratings by all subjects).

Examination of the data in Table 7 reveals the ratings to have general construct validity, because the rank order of geometric mean magnitude estimates corresponds to the generally understood and accepted semantic meaning of the phrases. Also, in keeping with previous findings concerning the non-equivalence of intervals between the labeled points on category scales, the data in Table 7 clearly demonstrate that the phrases used in Gagge's et al. [30] comfort sensation scale (asterisked) are not perceptually equivalent. For example, while the interval between the phrases "uncomfortable" and "very uncomfortable" is 113 units, the interval between the phrases "uncomfortable" and "slightly uncomfortable" is only 43 units. The data

also a reveal slight asymmetry between the ratings of comfort and discomfort. Examining common adjective phrases above and below the “neutral” and “neither comfortable nor uncomfortable” categories in Table 7 reveals that discomfort initially grows more quickly than comfort, i.e., “barely comfortable” = 15.42, “barely uncomfortable” = -27.61, “a little comfortable” = 28.77, “a little uncomfortable” = 40.90, “somewhat comfortable” = 59.98, and “somewhat uncomfortable” = -71.56. With some exceptions this difference can be observed throughout the scale. It is only at the highest levels of comfort/discomfort, i.e., “greatest possible” and “greatest imaginable”, that comfort ratings achieve the same levels of magnitude as ratings of discomfort.

**Table 7. Word phrases, geometric mean magnitude estimates, and standard errors divided by the geometric means for the data from Phase 3 (n=35).**

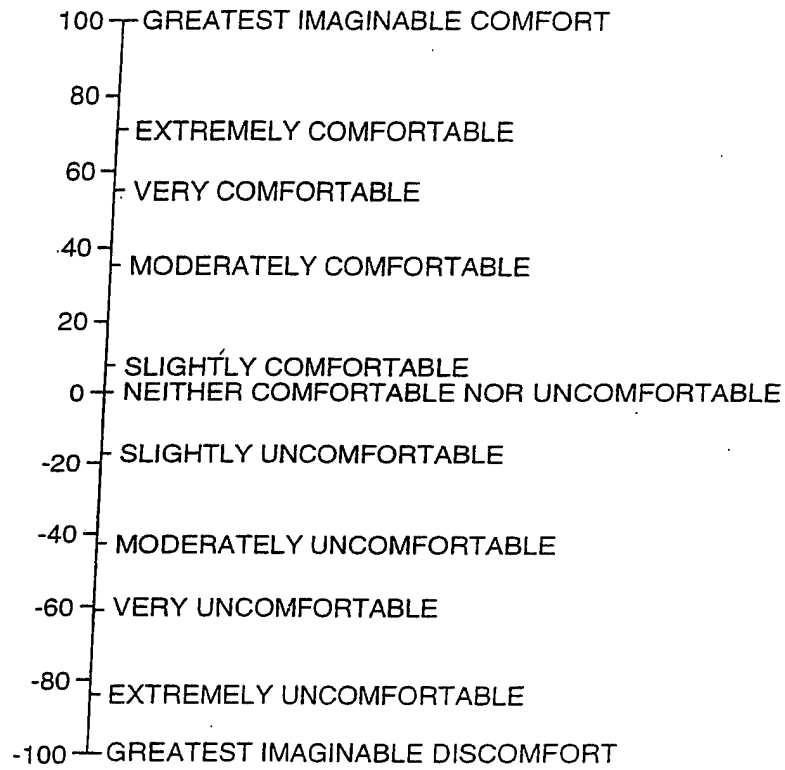
<u>Comfort/Discomfort Word Phrases</u>	<u>Geom. Mean Mag. Est</u>	<u>Standard Error</u>	<u>Standard Error/G.M.</u>
Greatest Imaginable Comfort	366.72	34.88	0.10
Greatest Possible Comfort	345.28	28.76	0.08
Exceptionally Comfortable	280.20	16.03	0.06
Superior Comfort	279.71	19.27	0.07
Intensely Comfortable	268.44	19.82	0.07
Extremely Comfortable	260.75	23.51	0.09
Highly Comfortable	224.01	15.80	0.07
Very Comfortable	203.99	13.96	0.07
Terribly Comfortable	135.93	48.72	0.36
Moderately Comfortable	130.18	10.51	0.08
Comfortable *	109.22	10.81	0.10
Satisfactory Comfort	86.11	11.68	0.14
Fairly Comfortable	85.16	8.62	0.10
Average Comfort	77.58	17.30	0.22
Acceptable Comfort	72.17	8.85	0.12
Somewhat Comfortable	59.98	9.07	0.15

<b>Slightly Comfortable</b>	38.26	9.96	0.06
<b>A Little Comfortable</b>	28.77	7.82	0.27
<b>Mediocre Comfort</b>	22.63	9.60	0.42
<b>Barely Comfortable</b>	15.42	4.77	0.31
<b>Neutral</b>	0	0	N.A.
<b>Neither Comfortable nor Uncomfortable</b>	0	0	N.A.
<b>Barely Uncomfortable</b>	-27.61	4.38	0.16
<b>A Little Uncomfortable</b>	-40.90	5.05	0.12
<b>Slightly Uncomfortable *</b>	-52.95	5.73	0.11
<b>Somewhat Uncomfortable</b>	-71.56	6.74	0.09
<b>Average Discomfort</b>	-76.64	13.55	0.18
<b>Mediocre Discomfort</b>	-79.56	10.96	0.14
<b>Uncomfortable *</b>	-96.34	8.21	0.09
<b>Fairly Uncomfortable</b>	-99.38	10.07	0.10
<b>Moderately Uncomfortable</b>	-145.63	7.23	0.05
<b>Very Uncomfortable *</b>	-209.86	11.00	0.05
<b>Awfully Uncomfortable</b>	-228.96	10.71	0.05
<b>Highly Uncomfortable</b>	-231.80	11.42	0.05
<b>Terribly Uncomfortable</b>	-257.78	14.51	0.06
<b>Exceptionally Uncomfortable</b>	-272.76	12.41	0.05
<b>Intensely Uncomfortable</b>	-274.34	18.28	0.07
<b>Oppressively Uncomfortable</b>	-279.70	15.71	0.06
<b>Horribly Uncomfortable</b>	-283.88	22.86	0.08
<b>Extremely Uncomfortable</b>	-290.84	15.57	0.05
<b>Unbearably Uncomfortable</b>	-298.44	21.79	0.07
<b>Greatest Possible Discomfort</b>	-345.82	24.29	0.07
<b>Greatest Imaginable Discomfort</b>	-350.67	35.85	0.10

Based on the data in Table 7, a sub-set of phrases were chosen to construct a labeled magnitude scale of comfort. The criteria for selection of terms were: 1) low variability in perceived semantic meaning; 2) creation of an equal number of comfortable and uncomfortable terms (a decision based on evidence from the preference scaling literature that shows that balanced scales are better for differentiating products); 3) the inclusion of a neutral term; and 4) parallelism in the adjectives used to qualify comfort and discomfort.

Examination of the standard errors of the geometric means (SEGM) for each of the phrases (Table 7) led to the elimination of several phrases (e.g., "mediocre comfort," "barely comfortable," "a little comfortable") due to their variable semantic meaning to subjects. Other phrases were eliminated because of a lack of bipolarity (e.g., "superior comfort," "oppressively uncomfortable"). Applying the remaining criteria to the phrases resulted in the selection of 11 phrases: five associated with comfort, five with discomfort, and one neutral term (neither comfortable nor uncomfortable). The geometric mean magnitude estimates of the positive and negative phrases were transformed to range from 0 to +100 (positive phrases) and 0 to -100 (negative phrases). The phrases were then placed along a 100mm vertical analogue line scale in accordance with their transformed values. The resultant scale of comfort is shown in Fig. 5.

The comfort affective labeled magnitude (CALM) scale shown in Fig. 5 has several advantages over other comfort scales used previously in the literature. Using this scale, the level of comfort or discomfort experienced by an individual can be easily indexed by simply placing a hash mark somewhere on the vertical line. This stands in contrast to the difficulty often encountered by subjects using magnitude estimation procedures. However, by having placed the phrases of comfort/discomfort along the analogue line scale at positions that represent the magnitude of their semantic meaning as determined by a magnitude estimation procedure, it becomes possible to treat the measured distances along the scale as ratio level data. This stands in stark contrast to category scales of comfort which provide only ordinal data. It also enables statements to be made about whether a particular sample is 20%, 40%, 3 times, etc. as comfortable (or uncomfortable) as another sample, but without requiring the normalization of data as with magnitude estimates. Lastly, by using the "greatest imaginable" comfort (or discomfort) as end-points on the scale, the scale enables better discrimination among samples/conditions that are either very high or very low in comfort/discomfort and establishes a common ruler by which comfort/discomfort ratings of different subjects can be compared.



**Figure 5.** The Comfort Affective Labeled Magnitude (CALM) scale.

## Experiment 2

Creating a labeled magnitude scale of comfort from the psychophysically determined semantic meaning of phrases is only the first step in creating an improved scale of comfort. The scale must also be shown to be valid, reliable, and sensitive to differences among stimuli that vary along the comfort/discomfort dimension. In order to evaluate the reliability, validity and sensitivity of the comfort affective labeled magnitude (CALM) scale that was developed in Experiment 1, a study was conducted in which subjects used the scale to index the comfort/discomfort associated with a variety of image-based clothing and environmental scenarios. The use of image-based stimuli in psychophysical scaling has been shown to produce similar data patterns as actual stimuli [55] and is a convenient approach for testing of such scale properties as validity, sensitivity and reliability.

**Methods:** Twenty-seven NATICK volunteer employees served as subjects. All were drawn from the same general subject pool as those used in Experiment 1. In order to establish a clear and unambiguous set of distinct comfort levels for testing the sensitivity of the scale, written comfort scenarios were developed that described a wide range of clothing and environmental conditions, using clothing type, ambient temperature, humidity, wind speed, and the activity of the subject as text variables. These six written scenarios are shown in Table 8. As can be seen, each scenario described a particular type of fabric (for a shirt or blouse) and a set of environmental/activity conditions in which the garment would be worn. The purpose of the scenarios was to create realistic, image-based stimuli that would be associated with discrete and distinct levels of perceived comfort/discomfort among all subjects. A meaningful scale of comfort should be able to discriminate among the levels of comfort/discomfort induced by the image-based stimuli and should be reliable from one judgment time to the next.

Subjects were tested in individual consumer testing booths. Each subject was given a self-administered questionnaire that included written instructions and a set of eight stimulus/response sheets (in random order) with the six scenarios (plus two repeated scenarios in order to obtain a measure of reliability) printed on them. Subjects were asked to rate the comfort or discomfort associated with each written scenario by simply placing a hash mark somewhere on the comfort affective labeled magnitude (CALM) scale (Fig. 5). However, since previous research has shown that the *numerical* labels placed along labeled affective magnitude scales do not affect ratings

(subjects attend to the verbal labels and extrapolate between them) [46, 47], the scale points were rescaled to range from 0 (“greatest imaginable discomfort”) to +100 (“greatest imaginable comfort”) so that subjects would not be unduly influenced to assign negative numerical ratings to negatively valenced scenarios and positive numerical ratings to positively valenced scenarios, independently of a considered evaluation of the comfort/discomfort levels evoked by the scenarios and the semantic implications of the verbal scale labels.

**Results/Discussion:** Data were analyzed by measuring the distances of the hash marks from the zero point along the rating scale. Frequency distributions for each scenario, analysis of variance (with Newman-Kuels post-hoc tests) across scenarios, and correlation coefficients between the replicated scenarios were computed.

**Table 8. The six written comfort scenarios used in Phase 2, Experiment 2.**

<b><u>Shirt/blouse Type</u></b>	<b><u>Conditions of Wear</u></b>
Hot Denim garment *	It is 100°F and 60% humidity, no wind. You are outside walking to the grocery store for 10 minutes.
Light Wool garment *	It is 0°F and 20% humidity, no wind. You are outside standing for 1/2 hour.
Clingy Cotton/polyester garment	It is 80°F and 50% humidity, no wind. You are outside mowing the lawn for 20 minutes.
Thin Polyester garment	It is 78°F and 30% humidity. You are inside and have been playing table tennis for 1/2 hour.
Light Cotton garment	It is 95°F and 20% humidity. You are driving a car, air conditioner blowing directly on you, sun shining through driver's window, for one hour.
Absorbent Cotton garment	It is 72°F and 30% humidity, no wind. You are outside sitting in the shade.

\* Scenarios that were evaluated twice to assess reliability of the CALM scale.

Examining the frequency distributions for the different scenarios revealed no unusual or unexpected distribution of values for any of the stimuli. The means and standard deviations of

the comfort ratings for the eight scenarios are shown in Table 9, along with the results of the Newman-Kuels post-hoc tests of differences between means. The mean comfort ratings of subjects differed significantly across scenarios ( $F=83.77$ ,  $df=7,175$ ,  $p<.001$ ), ranging from below “very uncomfortable” (the hot/denim scenario) to above “moderately comfortable” (the two cotton scenarios). Mean comfort ratings for the two replicated scenarios (hot/denim and light/wool) were nearly identical (Table 9). In addition, the Pearson product-moment correlation coefficient calculated across subjects for the two “hot denim” scenarios was 0.84 and between the two “light wool” scenarios was 0.94, both significantly different from zero at  $p<.0001$  level.

**Table 9. Means and standard deviations of comfort ratings for the 8 scenarios used in Experiment 2, Phase 3 (n=26).**

<u>Scenarios</u>	<u>Mean*</u>	<u>Standard Deviation</u>
Hot Denim (initial)	15.7 <sup>a</sup>	7.8
Hot Denim (repeated)	16.1 <sup>a</sup>	9.0
Light Wool (initial)	19.3 <sup>a</sup>	14.4
Light Wool (repeated)	20.4 <sup>a</sup>	15.4
Clingy Cott/Poly	28.6 <sup>b</sup>	16.5
Thin Polyester	41.4 <sup>c</sup>	16.7
Light Cotton	70.8 <sup>d</sup>	18.2
Absorbent Cotton	75.5 <sup>d</sup>	16.3

\* Means with different letter superscripts are significantly different at  $p<.05$ .

Examining the tables and considering the  $r$ 's between replicated scenarios it can be concluded that 1) there was a wide range of comfort ratings assigned to the different comfort scenarios and that these ratings are consistent with the logically expected levels of comfort defined by the scenario, 2) there are significant differences among pairs of scenarios that would be expected to differ; and 3) the correlations among the replicated scenarios are very high. Taken together, these data show a high degree of sensitivity of the CALM scale to image-based scenarios that would normally be considered to generate differences in comfort levels, a high degree of construct validity because the mean comfort ratings of the scenarios are logically

ordered, and good test-retest reliability.

### Experiment 3

The results of Experiment 2 support the sensitivity, validity and reliability of using the CALM scale to rate the comfort/discomfort of image-based stimuli. However, before applying the CALM scale to the evaluation of the test fabrics for which sensory handfeel attributes were characterized in Phase 1, a study was conducted to assess the reliability and sensitivity of the CALM scale when used to rate the comfort of gloves made from different fabrics. Gloves were chosen as stimuli because they are the item of clothing that generates comfort responses most similar to what would be experienced in handling fabric swatches.

**Methods:** Thirty-seven volunteer consumer panelists served as subjects. Consumer subjects came from the same pool of subjects described previously. All were naïve to the testing of the handfeel and comfort parameters of clothing and fabrics. The stimuli consisted of 3 gloves that differed in both fabric and construction. One was an 8-ounce jersey fabric glove with a knit wrist, clute cut (Dickey brand, general utility Williamson-Dickey Mfg Co.). The second was an 8 oz blended canvas glove with a knit wrist (Wells-Lamont “Basics” work glove, 65% polyester, 35% cotton, Wells-Lamont, Inc. Niles, IL), and the third was a U.S. military glove insert made of 70% wool and 30% nylon.

All testing was done in the same consumer testing booth (70°F) used in Experiment 2, in order to ensure sample constancy and to avoid potential influences of temperature variability on comfort ratings [52, 56]. Glove samples were presented sequentially in restricted random order (the same glove could not be presented sequentially) in two repeated series. Subjects were instructed to place the glove on their preferred hand (determined in advance) and to rate its comfort after clenching their fist 3 times. Subjects were specifically instructed to ignore fit in their evaluation of the glove’s comfort. Comfort ratings were made using the CALM scale (labeled –100 to +100). After evaluating the comfort of the three gloves in one series, ratings were repeated in a second test series using the same three gloves.

**Results/Discussion:** Table 10 shows the means and standard deviations of the comfort ratings for each replicate of the three gloves. As can be seen, the rank order of comfort ratings for the three gloves in increasing order was wool glove < canvas glove < jersey glove. Analysis

of variance showed a significant glove effect ( $F=52.23$ ,  $df = 2,72$ ,  $p<.001$ ). In addition, there was a significant session (replication) effect ( $F=13.17$ ,  $df = 1,36$ ,  $p<.001$ ) and a significant session x glove effect ( $F=17.96$ ,  $df = 2,72$ ,  $p<.001$ ). The latter effects can be attributed entirely to the difference in mean comfort ratings for the wool glove between replicates. This effect may be due to a greater variability in comfort sensation around the neutral point (neither comfortable nor uncomfortable), as reflected in the absolute comfort ratings and associated standard deviations in Table 10. Surprisingly, in spite of this session effect, the Pearson correlation coefficient across subjects for the two replicates of the wool glove was .93 ( $p<.01$ ). The correlation coefficient between replicates for the jersey glove was .88 ( $p<.01$ ) and for the canvas glove was .91 ( $p<.01$ ). The results of this study show the CALM scale to be a sensitive measure of the perceived comfort of fabrics/clothing worn on the hand. The correlation coefficients between replicates also show good reliability of the scale for this purpose, although the reliability may be reduced when comfort ratings fall near the neutral point.

**Table 10. Means, standard deviations, and standard errors of comfort ratings for the 3 gloves used in Phase 2, Experiment 3 (n=37).**

	Mean	Std Deviation	Standard Error of Mean
Replicate 1 - Jersey Glove	64.97	15.55	2.56
Replicate 2 - Jersey Glove	66.92	15.98	2.63
Riplicate 1 - Wool Glove	6.00	38.94	6.4
Replicate 2 - Wool Glove	-7.78	43.33	7.12
Replicate 1 - Canvas Glove	37.30	27.36	4.50
Replicate 2 - Canvas Glove	36.28	25.95	4.27

#### **Phase 4: Comfort Scaling of Military Fabrics: Reliability Measures and the Relationship to Sensory Handfeel Characteristics**

In order to examine the relationship of sensory handfeel attributes to clothing comfort, the same 13 fabrics for which descriptive handfeel data were generated in Phase 2 were evaluated for their handfeel comfort by naïve consumers.

**Methods:** Forty civilian employees of NATICK who had no formal training in textiles

were recruited as subjects from the same population pool described previously. The same 30cm x 30cm swatches of each of the fabrics that were used in Phase 2 (see Table 4) were used as stimuli. All samples were stored under controlled climatic conditions ( $70^{\circ} \pm 1.4$  F /  $65 \pm 1.3$  % RH) until just prior to testing. Testing was conducted in the same temperature controlled, individual sensory testing booths used in previous consumer tests.

All 13 samples were presented in random order during a single test session. Each sample was evaluated for its comfort using the same version of the CALM scale used in Experiment 3/Phase 3. Subjects were instructed that they could “hold, touch, feel or squeeze the material in any manner” so long as they only felt and evaluated the coded (face) side of the fabric. After evaluating each sample for its comfort as felt by the hand, the sample and the rating form were returned through the hood and the next sample was presented. Testing was repeated in exactly the same manner with the same subjects 5 days after initial testing in order to assess the reliability of subject ratings.

**Results/Discussion:** The sensory data from Phase 2 were used to correlate with the consumer comfort data collected here. In addition, for each fabric, the mean descriptive attribute intensity rating across all attributes was calculated from the Phase 2 data. This was done to create an index of the overall salience of the fabric’s handfeel, in order to test the hypothesis that clothing comfort is related to the *absence of tactile sensation*. Such an hypothesis derives from such studies as those of Gwosdow, et al. (52) in which increased perception of fabric texture significantly decreased fabric acceptability. In order to test this hypothesis, the calculated index was correlated with consumer comfort ratings.

Table 11 shows the mean comfort ratings for each of the 13 test fabrics and the results of ANOVA and post-hoc tests conducted on the differences in mean comfort ratings. It is evident from examination of Table 11 that the CALM scale significantly differentiated among the comfort levels of the fabrics. In terms of absolute comfort levels, the fabrics had a range of perceived comfort/discomfort that varied from slight discomfort to above moderately comfortable. (Note that these fabrics were all selected from materials already in use in military garments, so very uncomfortable fabrics would not be expected to be part of the stimulus set).

A Pearson product-moment correlation coefficient calculated between comfort ratings obtained during the initial test session and the replication conducted five days later had a value of

.68 ( $p < .01$ ). Although not as high as the test-retest correlation coefficients found for the CALM scale when applied to image-based stimuli (Experiment 2, Phase 3) and gloves (Experiment 3, Phase 3), in those experiments judgments were repeated within a single session, whereas, in this experiment judgments were separated by a 5-day interval.

**Table 11. Mean comfort ratings for the 13 fabric used in Experiment 3, Phase 3 (n=45).**

<u>Fabric</u>	<u>Mean Comfort Rating*</u>	<u>Standard Deviation</u>
18L	-9.8 <sup>a</sup>	44.8
17C	-1.4 <sup>ab</sup>	40.3
176	2.4 <sup>ab</sup>	29.4
124	9.8 <sup>bc</sup>	25.0
20J	10.9 <sup>bcd</sup>	31.0
16C	22.0 <sup>cde</sup>	26.2
12T	23.6 <sup>cde</sup>	27.1
14N	24.2 <sup>cde</sup>	30.8
19N	28.5 <sup>cdef</sup>	36.1
10R	28.9 <sup>def</sup>	25.7
13P	37.4 <sup>ef</sup>	25.3
15B	46.4 <sup>f</sup>	22.5
11A	47.2 <sup>f</sup>	27.8

\* Means with different letter superscripts are significantly different at  $p < 0.5$ .

Table 12 gives the Pearson correlation/coefficients of both the individual sensory handfeel attributes and the mean of all attribute intensity ratings for each sample (Phase 2) with the mean consumer comfort ratings obtained in the present experiment. It is evident from the data in Table 12 that many of the sensory attributes are significantly correlated with consumer comfort ratings. These include “gritty,” “tensile stretch,” “hand friction,” “depression depth,” and “springiness”. Also evident is the fact that all 17 of the descriptive handfeel attributes are

*negatively* correlated with comfort, suggesting that the higher the salience of any fabric attribute, the lower the perceived comfort. It is not surprising then, that the mean attribute intensity rating across all attributes accounts for about 50% of the variance in comfort ( $r = -.70$ ), even though it was not high enough to reach statistical significance.

**Table 12. Pearson product-moment correlation coefficients for individual handfeel attributes and for the mean intensity across all attributes with judged comfort.**

<u>Handfeel Attribute</u>	<u>r with Comfort</u>
Grainy	-.41
Gritty	-.92**
Fuzzy	-.60
Thickness	-.32
Tensile Stretch	-.92**
Hand Friction	-.77*
Fabric to Fabric Friction	-.36
Depression Depth	-.71*
Springiness	-.72*
Force to Gather	-.17
Stiffness	-.17
Force to Compress	-.17
Compression Resilience/Intensity	-.42
Compression Resilience/Rate	-.53
Fullness/Volume	-.17
Noise Intensity	-.25
Noise Pitch	-.03
Mean Intensity Over All Attributes	-.70

\*  $p < .05$

\*\* $p < .01$

## **Phase 5: Sensory-Instrumental (Kawabata) –Comfort Correlations**

From a purely logical standpoint, the sensory handfeel attributes of a fabric should be a better predictor of the comfort of the fabric than any mechanical measure performed on the fabric, because the human observer can only be basing his comfort judgment on perceptual experiences not any actual physical parameter of the fabric. Of course, mechanical measures of fabric properties are extremely convenient, and it would be desirable to find one or more mechanical measures that correlate well with either perceived sensory experience or comfort. For this reason the relationship of the mechanical parameters of fabrics to the sensory and comfort responses that they give rise to in humans is an area of continuing interest to textile researchers. This area of inquiry is also important as a potential aid in clothing and materials development, to enable the prediction of the effects of changes in fabric composition, weave and finish characteristics on perceived comfort. One instrumental technique that has achieved particular popularity in textile measurement is the Kawabata Evaluation System for Fabrics (KES-F) [48-50]. This technique consists of a set of measures of various mechanical parameters of fabrics that can then be combined, using regression formulas developed by Kawabata, to predict “hand” attributes. In particular, the methodology generates predictions for the following “hand” attributes: “stiffness”, “anti-stiffness”, “crispness”, “fullness and softness”, “smoothness”, and “total hand value”.

**Methods:** To assess the relationship between Kawabata parameters and the descriptive handfeel and comfort data generated previously, the eight fabrics listed in Table 4 were submitted to Kawabata mechanical testing. The testing was conducted by Milliken Research, Corp., under standardized textile testing conditions. Table 13 lists the Kawabata parameters that were tested and their associated units of measure. All testing was conducted on the reverse side of the fabric swatches. Due to the large number of mechanical properties tested (17) and the equally large number of descriptive handfeel attributes in the HSDA method (17), it is impractical to examine correlations among individual mechanical and handfeel properties. However, the Kawabata system enables the prediction of five “hand values” and a “total hand value” based on predictive equations from the mechanical parameters. These five “primary hand expressions” are based on the end-use of the fabrics and are listed in Table 14 as they apply to men’s winter and summer suit fabrics.

**Table 13. Kawabata parameters and associated units of measure.**

**Kawabata Mechanical Parameters**

<b><u>Blocked Property</u></b>	<b><u>Symbol</u></b>	<b><u>Characteristic Value</u></b>	<b><u>Unit</u></b>
<b>Tensile</b>	KEMT	Extensibility	gf - Dimensionless
	K_LT	Linearity	Dimensionless
	K_WT	Tensile energy	gf - cm/cm <sup>2</sup>
	K_RT	Resilience	%
<b>Bending</b>	K_B	Bending rigidity	gf-cm <sup>2</sup> /cm
	K_HB	Hysteresis	gf-cm <sup>2</sup> /cm
<b>Shearing</b>	K_G	Shear stiffness	gf/ cm - degree
	K_HG	Hysteresis at 0 = 0.5°	gf/ cm
	K_HG5	Hysteresis at 0 = 5°	gf/ cm
<b>Compression</b>	K-LC	Linearity	Dimensionless
	K_WC	Compressional energy	gf - cm/cm <sup>2</sup>
	K_RC	Resilience	%
<b>Surface</b>	K_MIU	Coefficient of friction	Dimensionless
	K_MMD	Mean deviation of MIU	Dimensionless
	K_SMD	Geometrical roughness	micron
<b>Weight &amp; Thickness</b>	K_W	Weight per unit	mg/cm <sup>2</sup>
	K_T	Thickness at 0.5 gf/cm <sup>2</sup>	mm

**Table 14. Definitions of primary hand expressions in the Kawabata system for the standard and analysis of hand evaluation.**

<b>Primary Hand Expression</b>	<b>Definition</b>
<b>Stiffness</b>	A feeling related with bending stiffness. Springy property promotes this feeling. The fabric having compact weaving density and woven by springy and elastic yarn makes this feeling strong.
<b>Anti-drape stiffness</b>	Anti-drape stiffness, no matter whether the fabric is springy or not. (This work means "spreading").
<b>Fullness and softness</b>	A feeling comes from bulky, rich and well formed feeling. Springy property in compression and thickness accompanied with warm feeling are closely related with this feeling. (Fukurami means "swelling").
<b>Crispness</b>	A feeling comes from crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn. This feeling brings us a cool feeling. (This word means a crisp, dry and sharp sound arisen by that the fabric is rubbed with itself).
<b>Smoothness</b>	A mixed feeling comes from smooth, limber and soft feeling. The fabric woven from cashmere fiber gives this feeling strongly.

**Results/Discussion:** Table 15 shows Pearson correlation coefficients between the Kawabata hand parameter predictions and the handfeel attributes ratings obtained on the same fabrics in Phase 2. Only correlation coefficients greater than .50 are listed.

Comparing the definitions of the primary hand expressions in Table 14 with the obtained correlations of these hand values with HSDA handfeel attributes, reveals good conceptual agreement. For example, both stiffness and anti-drape stiffness are correlated with the same six HSDA handfeel attributes, and the correlation with sensory "stiffness" is very high for both primary hand expressions. ( $r = .80, .84$ ). Similarly, for fullness/softness, the HSDA handfeel attributes that correlate highly with it are those related to "bulky", "rich" and "springy" sensations. Lastly, smoothness, which is defined as "limber" and "soft" like "cashmere fiber", is correlated most highly with "fuzzy" and "fabric to fabric friction", both of which would be expected to increase with softer pile fabrics.

While the Kawabata method predicts hand values from independent mechanical properties of the fabrics, they are based on predictive equations derived from quite different fabrics than were tested here. A more direct approach to reduce the number of Kawabata mechanical properties to a manageable number for correlation with sensory or comfort data is to use Principal Component Analysis (PCA) to derive the component (factor) structure in the data. Such an approach can also be used to reduce the redundancy in the sensory handfeel data.

A PCA analysis was conducted on the Kawabata data obtained on the eight fabrics. A Varimax rotation with Kaiser normalization and an Eigen value criterion of 1.0 to stop extracting factors resulted in a five component solution (Table 16). An analysis of the variable loadings resulted in an interpretation of these components as being related to "shear properties" (Component 1), "binding properties" (Component 2), "compression/friction" (Component 3), "tensile properties" (Component 4) and "surface roughness" (Component 5). These five components accounted for 98% of the variance in the data.

**Table 15. Pearson correlation coefficients (> .50) between Kawabata hand values and handfeel attributes evaluated by the HSDA method.**

<b>Stiffness</b>	Force to compress	.83*
	Stiffness	.80*
	Force to gather	.79*
	Compression resilience intensity	.71
	Thickness	.68
	Fullness/volume	.63
<b>Anti-drape stiffness</b>	Force to compress	.87*
	Stiffness	.84*
	Force to gather	.80*
	Compression resilience intensity	.73*
	Fullness/volume	.71*
	Thickness	.67
<b>Fullness/softness</b>	Springiness	.87*
	Depression depth	.85*
	Fuzzy	.85*
	Hand Friction	.77*
	Gritty	.76*
	Tensile stretch	.67
<b>Smoothness</b>	Fuzzy	.55
	Fabric to fabric friction	.50
<b>Crispness</b>	No correlation > .50	

\*  $p < .05$

**Table 16. Rotated PCA matrix for Kawabata mechanical parameters.\***

	Components				
	1	2	3	4	5
Linearity	.926				
Resilience	-.915				
Hysteresis at 0 = 0.5°	.901				
Hysteresis at 0 = 5°	.871				
Compressional energy	-.870				
Thickness at 0.5 gf/cm <sup>2</sup>	-.832				
Shear stiffness	.810				
Resilience	-.775		.566		
Weight per unit area		.933			
Bending rigidity		.862			
Hysteresis		.844			
Linearity			.949		
Coefficient of friction			.931		
Tensile energy				.953	
Extensibility				.948	
Mean deviation of MIU					.924
Geometrical roughness					.812

\* Rotation converged in 9 iterations.

**Table 17. Rotated PCA matrix for HSDA handfeel attributes.\***

	Components		
	1	2	3
Gritty	.971		
Springiness	.944		
Depression Depth	.926		
Fuzzy	.899		
Tensile Stretch	.898		
Hand Friction	.887		
Compression Resilience: Rate	.717		
Fabric to Fabric Friction	.676		
Force to Compress		.973	
Force to Gather		.954	
Fullness/volume		.935	
Stiffness		.908	
Compression Resilience: Intensity		.904	
Thickness		.900	
Noise Intensity			.919
Noise Pitch			.839
Grainy			.809

\*Rotation converged in 7 iterations.

A similar PCA was conducted on the sensory descriptive handfeel data obtained during Phase 1 testing. This analysis resulted in the 3 component solution depicted in Table 17. The three components accounted for 92% of the variance in the data set. Analysis of the attribute loadings on each component resulted in the identification of the three components as “surface texture/depth” (Component 1), “volume” (Component 2) and “noise” (Component 3).

In order to assess the relationship of sensory attributes to comfort ratings, a PCA was conducted using both the sensory attributes and “comfort” ratings. The results showed comfort ratings to load heavily (negative weight) on Component 1 (Table 18), suggesting that comfort is inversely related to perceived surface texture/depth. This is consistent with the data in Table 12 showing that the more salient is *any* attribute, the lower is the perceived comfort of the fabric.

**Table 18. Rotated PCA matrix resulting ffor HSDA handfeel attributes plus comfort.\***

	Components		
	1	2	3
Gritty	.990		
Tensile Stretch	.937		
COMFORT	-.919		
Springiness	.901		
Depression Depth	.879		
Hand Friction	.862		
Fuzzy	.835		-.527
Compression Resilience: Rate	.660		
Fabric to Fabric Friction	.589		
Force to Compress		.975	
Force to Gather		.962	
Fullness/volume		.931	
Thickness		.917	
Compression Resilience: Intensity		.915	
Stiffness		.908	
Noise Intensity			.923
Noise Pitch			.883
Grainy			.780

\* Rotation converged in 8 iterations.

**Table 19. Rotated PCA matrix for Kawabata mechanical parameters plus comfort.\***

	Components				
	1	2	3	4	5
Hysteresis at 0 = 0.5°	.939				
Resilience	-.923				
Linearity	.898				
Hysteresis at 0 = 5°	.864				
Shear Stiffness	.835				
Compressional energy	-.828				
Thickness of 0.5 gf/cm <sup>2</sup>	-.786				
Resilience	-.749			.592	
Weight per unit area		.918			
Bending rigidity		.881			
Hysteresis		.848			
Extensibility			.961		
Tensile energy			.932		
COMFORT	.594		-.748		
Linearity				.957	
Coefficient of friction				.926	
Mean deviation of MIU					.927
Geometric roughness					.819

\* Rotation converged in 8 iterations.

Lastly, a PCA was conducted using both the Kawabata data and the comfort ratings. The PCA, which again accounted for 98% of the variance in the data, revealed comfort to be positively loaded on Component 1 (shear), but negatively loaded on Component 4 (compression/friction) (Table 19). (Note that Component 4 in this PCA is the same in terms of loading variables as Component 3 in Table 16).

With independent component scores established from the principal component analysis for both the Kawabata and sensory handfeel data it was possible to predict perceived comfort from either the sensory component scores, the Kawabata component scores, or both. First, by including all three sensory components into a multiple regression of component scores on comfort ratings, the following regression equation (1) was determined:

$$\text{COMFORT} = -15.6 (\text{surface texture/depth}) - 1.07 (\text{volume}) - 7.67 (\text{noise}) + 27.5$$

(constant) ( $R = .96$ ;  $R^2_{\text{Adj}} = .87$ ). (1)

The weightings of the components in this regression model support the findings observed from the PCA of sensory attributes plus comfort, which showed the comfort variable to be loaded highly on Component 1 (resilience). In addition, the fact that all the component weightings are negative again supports the notion put forth earlier, that comfort is inversely related to the average perceived intensity of all handfeel attributes.

A multiple regression using the Kawabata component scores to predict comfort produced the following regression equation (2):

$$\text{COMFORT} = 11.8 (\text{shear}) - 3.1 (\text{bending}) - 0.3 (\text{compression/friction}) - 11.9 (\text{tensile}) + 0.4 (\text{surface roughness}) + 27.5 (\text{constant}) \quad (R = .94; R^2_{\text{Adj}} = .60) \quad (2)$$

While producing as good a predictive model as the sensory component scores, the Kawabata regression model utilized all five factors. Since there were only eight fabrics for purposes of prediction, it is not as compelling or as useful a model. In addition, none of the components were significant at the  $p < .05$  level, as compared to the sensory regression model in which only Component 2 (volume) was not statistically significant.

Combining both the sensory component scores and the Kawabata component scores into a stepwise multiple regression model to predict comfort resulted in the following equation (3):

$$\text{COMFORT} = -16.3 (\text{sensory surface texture/depth}) - 8.7 (\text{sensory noise}) - 4.3 (\text{Kawabata surface texture}) + 27.5 (\text{constant}) \quad (R = .99; R^2_{\text{Adj}} = .96) \quad (3)$$

where all three components contributed significantly ( $p < .05$ ) to the model. This three variable solution was chosen, because including more variables resulted in solutions that were overdetermined. As might well be expected, given that the comfort ratings were made by consumers who held the fabrics in their hands, both sensory surface texture and Kawabata surface texture factors were important predictors of comfort in the model. In addition, the noise factor was important sensory predictor of comfort due to its unique contribution to the model variance.

The reader may have noted that all of the sensory handfeel data collected and reported in Phases 1-4 were obtained for the face surface of the test fabrics, whereas, the Kawabata data was obtained from the reverse side of the fabrics. Although there were no obvious tactile differences between the face and reverse surfaces of these fabrics, in order to ensure that any possible such differences would not alter the basic findings of the research, the descriptive handfeel panel evaluated the reverse surfaces of all 8 test fabrics used in Kawabata comparisons. Each fabric

swatch was evaluated for 8 attributes that could potentially vary between face and reverse surfaces. Of the 64 *possible* differences between face and reverse (8 fabrics x 8 attributes), only 7 significant differences were found. The absolute magnitude of these differences were small (the largest was equal to one-half a scale point) and did not change the overall tactile profile for any fabric. It should be noted that for any other types of fabrics, differences between face and reverse surfaces could contribute more importantly to the interpretation of such data.

## DISCUSSION AND CONCLUSIONS

The research reported here forms the basis for a standardized approach to the characterization of clothing fabrics and the analysis of the contribution of their sensory and mechanical properties to perceived comfort. Although developed and applied for the characterization and analysis of military fabrics, the approach and techniques can be utilized for any clothing fabrics. The approach is predicated on the use of sound psychophysical principles for assessing both the qualitative and quantitative aspects of sensory handfeel and comfort experience.

The adaptation of the HSDA method of handfeel analysis to military fabrics constitutes a significant advance in enabling the sensory characterization of fabrics using a set of well-defined, independent attributes, each with a detailed operational technique for their evaluation. These standardized operational techniques enable ready transfer of the methodology to other laboratories. This, combined with the use of stimulus-referenced intensity scales for each attribute, establishes a unique, standard protocol for use in inter-laboratory studies or for use in establishing functional performance-based specifications for military (or other) clothing fabrics. In addition, the extremely high reliability of the method ensures that data collected over long periods of time, e.g., during storage trials, can be readily compared.

The experiments reported here have also detailed the development of an alternative scale for the assessment of comfort; one that is modeled after the category ratio scale of Borg [45] and the labeled magnitude scales of Green, et al. [46] and Schutz and Cardello [47]. While the latter scales were developed for the purpose of scaling perceived exertion, oral sensation intensity, and liking/disliking, the present CALM (Comfort Affective Labeled Magnitude) scale was developed specifically for the purpose of scaling perceived comfort/discomfort.

The CALM scale developed here has several important advantages over simple category scales of comfort. First, the CALM scale enables statements to be made about the ratios of perceived comfort among samples (at least to the same degree that magnitude estimation enables this). However, it avoids a major disadvantage of magnitude estimation; namely, the inability to index and compare absolute levels of liking among different individuals. The CALM scale avoids this problem by using the word phrases “greatest imaginable comfort” and “greatest imaginable discomfort” to anchor the scales to a common ruler of perceptual experience [45]. Another related advantage of the CALM scale is its potential greater sensitivity to differences among very comfortable (or uncomfortable) stimuli. This is a logical consequence of the CALM scale end-points (“greatest imaginable liking/disliking”) that enable more extreme ratings than “extremely comfortable (or uncomfortable)”. Thus, these end-points labels serve not only to anchor different subject ratings to a common scale, but also to foster better discrimination of very comfortable (or uncomfortable) fabrics or items of clothing. This can be an important advantage, because in most product development and evaluation situations the samples being tested are near optimal comfort. The CALM scale has the potential to enable better discrimination among fabrics and clothing items that fall in this “near optimal” category.

From both a sensitivity and reliability standpoint, the data obtained in Phases 3 and 4 show the CALM scale to be sensitive to a wide variety of comfort-related stimuli, including image-based stimuli, fabrics, and garments (gloves), and to have good reliability both within and across test sessions. In addition, a practical aspect of the scale is that a simple arithmetic mean can be used as a measure of central tendency. This stands in contrast to magnitude estimation, where medians, geometric means, or log transformations of the data must be calculated to arrive at a measure of central tendency. Also, because the scale produces ratio level data, standard parametric statistics can be used for analysis of the data.

Lastly, of some additional importance is the fact that the specific numerical labels that appear on the CALM scale are somewhat arbitrary. In previous research it has been shown that a scale with no numbers produces equivalent data to scales labeled with numbers that range from 0 to 100 or -100 to +100 [47]. Thus, it appears that subjects pay relatively little attention to the numbers on the scale, as suggested previously by Green, et al. [46]. It may well be the case that no numbers is the best option in certain cases. This is particularly true if the data from the scale are to be compared among users who differ significantly in their knowledge or use of numbers

(children versus adults) or where cultural or practical concerns may make the numbers more of a distraction. When no numbers are used, data from the scale can simply be transcribed from measurements made with a ruler on the 100mm analogue line scale and then transformed to a -100 to +100 scale. Of course, if it is desired to make ratio statements about liking/disliking, the scale must conform to the numerical values that were originally used to locate the semantic labels, (Fig 5), or to a multiplicative transformation of these values.

The approach to uncovering sensory instrumental-comfort relationships outlined in Phase 5 is also a valuable approach to understanding the complex factors that contribute to the perceived comfort of fabrics and clothing. By reducing the multitude of sensory and mechanical properties that can be measured for fabrics to a small number of independent components, it is possible to derive regression models to predict the perceived comfort of the fabrics. The results of this research, as reported here, show that a judicious combination of sensory and instrumental factors can be used to predict the handfeel comfort of fabrics, while accounting for >95% of the variance in the comfort ratings.

Further research is now being conducted to determine the extent to which the sensory, instrumental, and handfeel comfort data collected here can be used to predict the dynamic comfort of users wearing garments constructed from these same fabrics in controlled wear trials.

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## **Appendix**

Instructions used to collect magnitude estimation data in Phase 3, Experiment 1

## Instructions

In this test we would like to obtain your opinion about the meaning of different words and phrases that could be used to describe one's feelings about the comfort or discomfort of clothing.

In order to obtain your opinions about these words and phrases, we are going to use a special method that allows you to indicate the magnitude of comfort or discomfort associated with each word/phrase by assigning numbers to them.

On each of the pages that follow, you will find a word/phrase that is/are used to describe comfort/discomfort feelings towards clothing. Next to it will appear two blank lines as in the following example:

	<b>+, -, 0</b>	<b>How Much</b>
<b>Extremely Comfortable</b>	_____	_____

After reading the phrase, the first thing you must do is assess whether the phrase is positive (+), negative (-), or neutral (0) in terms of the comfort – discomfort dimension. If you feel that the phrase suggests some degree comfort toward clothing, you would place a positive sign (+) on the first line after the phrase. If on the other hand, you feel that the phrase suggests some degree of discomfort for clothing, you would put a negative sign (-) on the first line after the phrase. If the phrase does not strike you as suggesting either comfort or discomfort, but rather is a “neutral” phrase, you should put a zero (0) on this line.

After having determined whether the phrase is positive, negative or neutral and writing the appropriate symbol (+, -, 0) on the first line, you will then assess the strength or magnitude of the comfort or discomfort reflected by the phrase. You will do this by placing a number on the second blank line (under “How Much”). For the first phrase that you rate, you can write any number you want on the line. We suggest you do not use a small number for this word/phrase. The reason for this is that subsequent words/phrases may reflect much lower strengths of comfort or discomfort. Aside from this restriction, you can use any number you want. For each subsequent word/phrase, your numerical judgment should be made proportionally and in comparison to the first number. That is, if you assigned the number 800 to index the strength of the comfort/discomfort denoted by the first word/phrase and the strength of comfort/discomfort

denoted by the second word/phrase twice as great, you would assign it the number 1600. If it were three times as great, you would assign it the number 2400, etc. Similarly, if the second word/phrase denoted only 1/10 the magnitude of comfort/discomfort as the first, you would assign it the number 80 and so forth. If any word/phrase is judged to be "neutral" (zero (0) on the first line), it should also be given a zero for its magnitude rating.

**Remember:** Proceed through each word/phrase by first judging whether it is positive (+), negative (-), or neutral (0) in nature, and then rate the strength of liking or disliking reflected by the word/phrase by assigning a number to it that stands in the same ratio to the number assigned to the first word/phrase as is its magnitude of comfort/discomfort to the magnitude of comfort/discomfort for the first word/phrase.

**If you have any questions, please ask them before you begin. Thank you.**